



# **Effect of the FlashJet Paint Removal System on Rotor Blade Skin Materials**

**by Scott Grendahl**

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**ARL-TR-4003**

**December 2006**

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# **Army Research Laboratory**

Aberdeen Proving Ground, MD 21005-5069

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**ARL-TR-4003****December 2006**

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**Scott Grendahl**

**Weapons and Materials Research Directorate, ARL**

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14. ABSTRACT The U.S. Army Aviation and Missile Research, Development, and Engineering Command in Huntsville, AL, requested the U.S. Army Research Laboratory Weapons and Materials Research Directorate at Aberdeen Proving Ground, MD, to develop and execute a program aimed at evaluating the effect of the FlashJet coating removal system on the mechanical properties of the typical U.S. Army aviation blade skin materials. The skin materials representative of the three most common U.S. Army helicopters were assessed. Fatigue, tensile, and short-beam shear tests were conducted. Test panels from six specimen groups were evaluated: baseline (as-painted), hand-sanded, stripped-to-primer, stripped-to-substrate, stripped-to-substrate plus two additional passes, and lifecycle.					
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## Contents

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<b>List of Figures</b>	<b>iv</b>
<b>List of Tables</b>	<b>v</b>
<b>1. Objective</b>	<b>1</b>
<b>2. Materials</b>	<b>1</b>
<b>3. Experimental Procedure</b>	<b>1</b>
<b>4. Results</b>	<b>2</b>
4.1 Short-Beam Shear.....	2
4.2 Tensile Testing .....	14
4.3 Fatigue Testing .....	14
<b>5. Discussion</b>	<b>24</b>
5.1 Short-Beam Shear.....	24
5.2 Tensile Testing .....	24
5.3 Fatigue Testing .....	24
<b>6. Conclusions</b>	<b>25</b>
<b>7. References</b>	<b>26</b>
<b>Distribution List</b>	<b>27</b>

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## List of Figures

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Figure 1. As-received 5216 E glass panel A.....	3
Figure 2. As-received 5216 E glass panel B. ....	3
Figure 3. As-received 5216 E glass panel C. ....	4
Figure 4. As-received 5216 E glass panel D. ....	4
Figure 5. As-received 5216 E glass panel E. ....	5
Figure 6. As-received 5216 E glass panel F. ....	5
Figure 7. As-received 5216 S glass panel A. ....	6
Figure 8. As-received 5216 S glass panel B. ....	6
Figure 9. As-received 5216 S glass panel C. ....	7
Figure 10. As-received 5216 S glass panel D. ....	7
Figure 11. As-received 5216 S glass panel E. ....	8
Figure 12. As-received 5216 S glass panel F. ....	8
Figure 13. As-received 114 E glass panel A. ....	9
Figure 14. As-received 114 E glass panel B. ....	9
Figure 15. As-received 114 E glass panel C. ....	10
Figure 16. As-received 114 E glass panel D. ....	10
Figure 17. As-received 114 E glass panel E. ....	11
Figure 18. As-received 114 E glass panel F. ....	11
Figure 19. Short-beam shear test results for 5216 E glass. ....	12
Figure 20. Short-beam shear test results for 5216 S glass. ....	12
Figure 21. Short-beam shear test results for 114 E glass. ....	13
Figure 22. Tensile test results for 5216 E glass. ....	14
Figure 23. Tensile test results for 5216 S glass. ....	15
Figure 24. Tensile test results for 114 E glass. ....	15
Figure 25. Fatigue test results for 5216 E glass. ....	16
Figure 26. Fatigue test results for 5216 S glass. ....	17
Figure 27. Fatigue test results for 114 E glass. ....	17

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## List of Tables

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Table 1. Composite materials. ....	1
Table 2. Composite test groups.....	2
Table 3. Short-beam shear results.....	13
Table 4. Tensile testing results.....	16
Table 5. Fatigue results for 5216 E glass.....	18
Table 6. Fatigue results for 5216 S glass. ....	20
Table 7. Fatigue results for 114 E glass.....	22

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## 1. Objective

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The objective of this study was to assess the effect of the FlashJet coating removal system on the mechanical properties of U.S. Army aviation blade skin materials.

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## 2. Materials

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The materials utilized within this work were representative of the materials used in the manufacture of the rotor blades from the CH-47 Chinook, the AH-64 Apache, and the UH-60 Blackhawk. Table 1 depicts the materials utilized within this work.

Table 1. Composite materials.

Platform	Material	Lay-up	Material Specification
CH-47	E-glass/5216 from Cytec, Anaheim, CA	2 plies, $\pm 45^\circ$	BMS8-196, Type III, Class A, Grade 1 (1)
AH-64	S-2 Glass/5216 from Cytec, Anaheim, CA	0/90/0°, 0° in spar direction	HMS 16-1113, Type 1 (2)
UH-60	E-glass/Cycom 114 from Cytec, Greenville, TX (Cycom 114/1062 W462 24 in E-glass)	(90/-30/30) <sub>s</sub>	SS9610-001 CYCOM 114, 1 sheet 24 × 24 in (3)

The coating system applied to the composite panels consisted of MIL-P-23377 (4) primer to a dry film thickness (DFT) of 0.0010–0.0015 in and MIL-P-46168 (5) top coat to a DFT of 0.0020–0.0025 in. The coating system was air dried for one week and then baked at 150 °F for 1 week to insure adequate curing.

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## 3. Experimental Procedure

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Composite panels were manufactured in accordance with the lay-up in table 1. All panels were cured via autoclave in accordance with the manufacturer's recommendations and governing documentation. The panels were painted and cured at Corpus Christi Army Depot (CCAD). CCAD processed the panels via the on-site FlashJet system and hand-sanding process in accordance with table 2.

Table 2. Composite test groups.

Process	Material	Process Notes
Group A Hand-sanding	5216 E glass 5216 S glass 114 E glass	Manual hand-sanding process by CCAD personnel in the composite shop.
Group B As-painted	5216 E glass 5216 S glass 114 E glass	Tested in the as-painted condition.
Group C Stripped to primer	5216 E glass 5216 S glass 114 E glass	Utilized FlashJet to remove just the topcoat.
Group D Stripped to substrate	5216 E glass 5216 S glass 114 E glass	Utilized FlashJet to remove both the topcoat and primer.
Group E Stripped to substrate plus two additional passes.	5216 E glass 5216 S glass 114 E glass	Utilized FlashJet to remove both paint layers and then two additional passes under the same conditions.
Group F Lifecycle—stripped and re-painted five times.	5216 E glass 5216 S glass 114 E glass	Utilized FlashJet to remove both paint layers then re-painting for five iterations.

The parameters of the FlashJet process were approximately 2000 V, 1 in/s travel speed, and 4-Hz xenon bulb frequency. In some cases, the voltage was slightly increased when removal was not fully achieved. The stripped panels were shipped to the U. S. Army Research Laboratory from CCAD for sectioning and mechanical testing. The as-received panels utilized for testing are presented in figures 1–18. The panels are also shown in their sectioned state in these figures.

The mechanical testing performed included tensile testing, fatigue testing, and short beam shear testing. These tests were conducted in accordance with the ASTM standards, ASTM-D-3039 (6), ASTM-D-3479 (7), and ASTM-D-2344 (8), respectively. The edges were polished through 1200-grit SiC paper to assist in individual ply observation. Tensile and short-beam shear testing were conducted at 0.05 in/min. Fatigue testing was conducted at 20 Hz and at  $R = 0.1$ .

## 4. Results

### 4.1 Short-Beam Shear

The short-beam shear results are presented in figures 19–21 and also tabulated in table 3. The “baseline” and “stripped-to-primer” groups had the highest short-beam shear strength values during the testing. In general, the “hand-sanded” group had the lowest strength values.

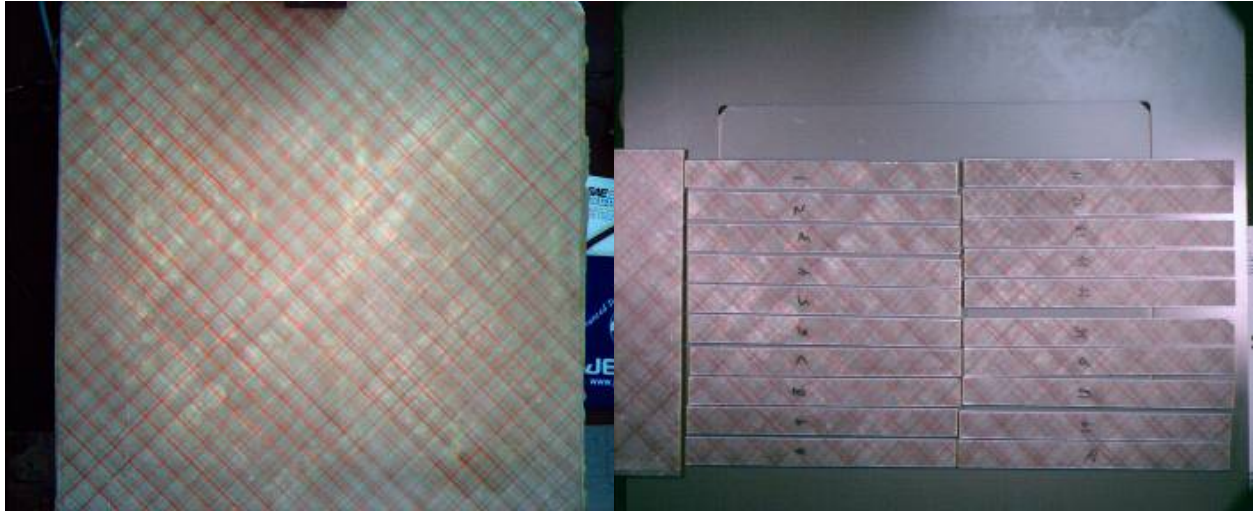


Figure 1. As-received 5216 E glass panel A.



Figure 2. As-received 5216 E glass panel B.

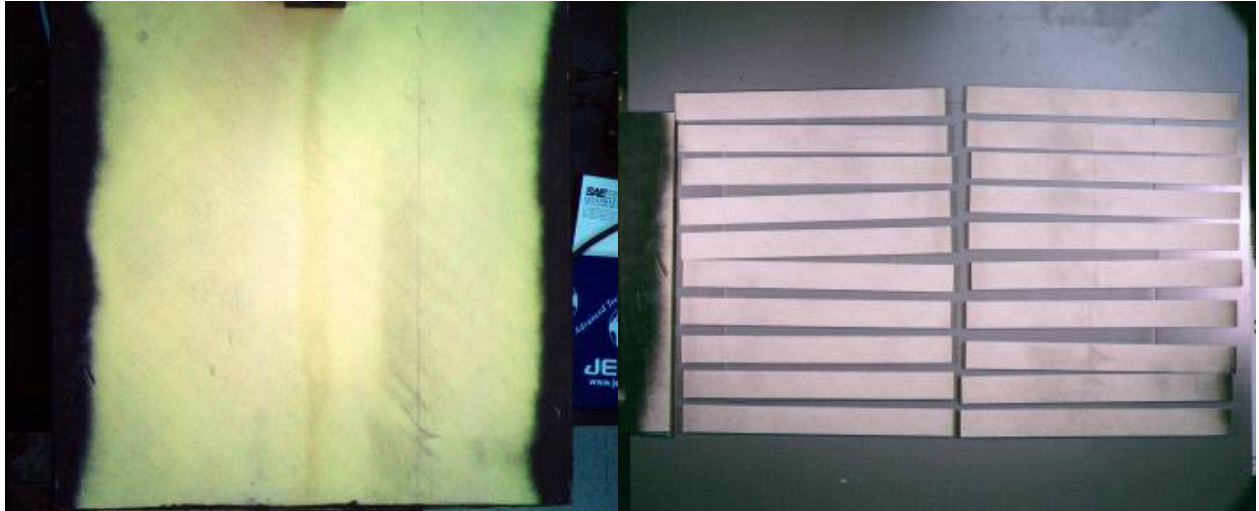


Figure 3. As-received 5216 E glass panel C.

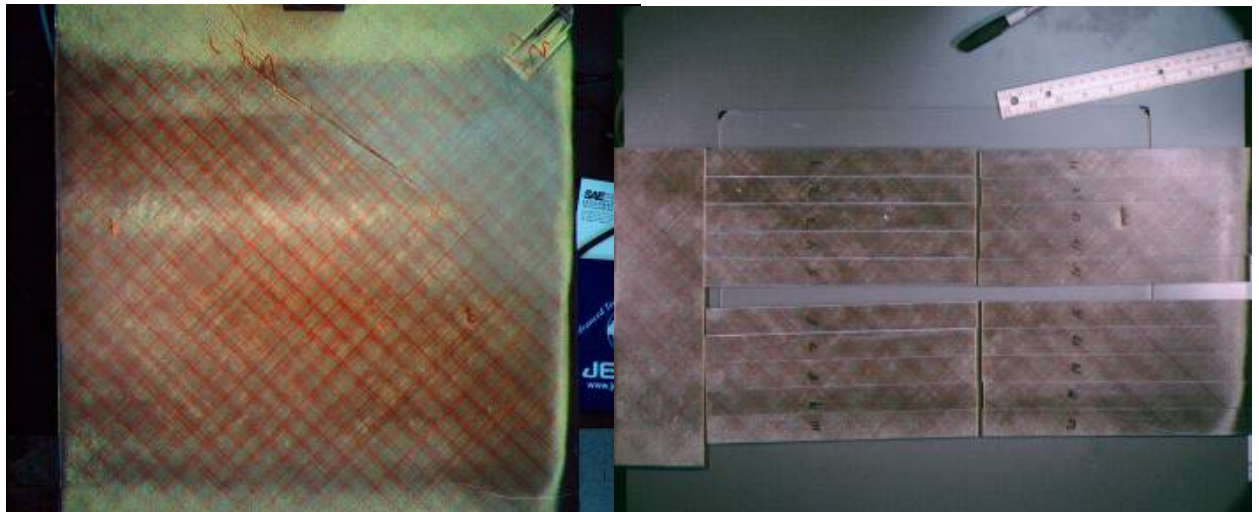


Figure 4. As-received 5216 E glass panel D.

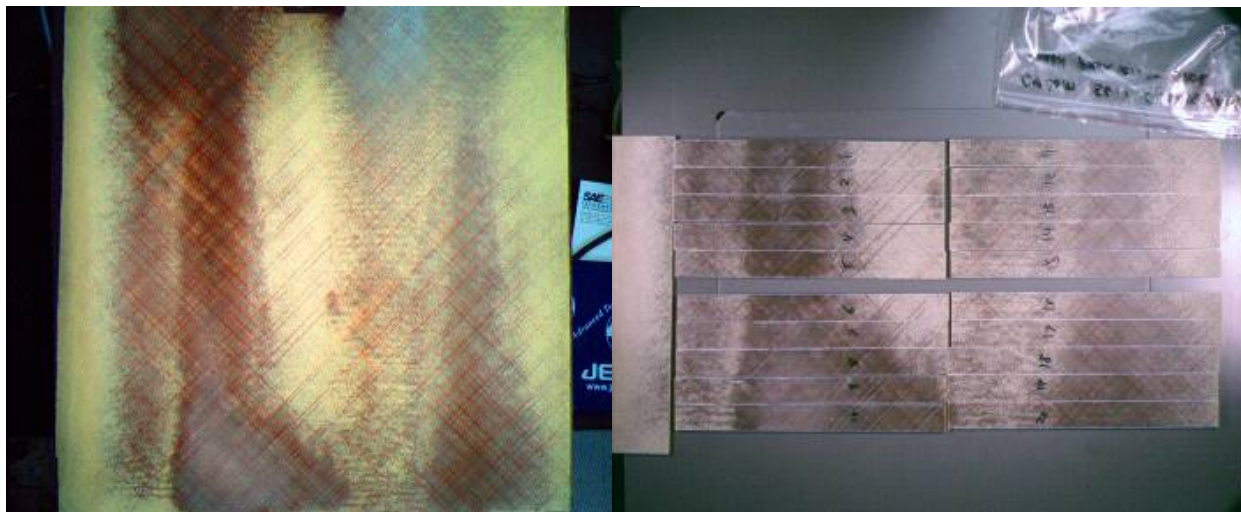


Figure 5. As-received 5216 E glass panel E.

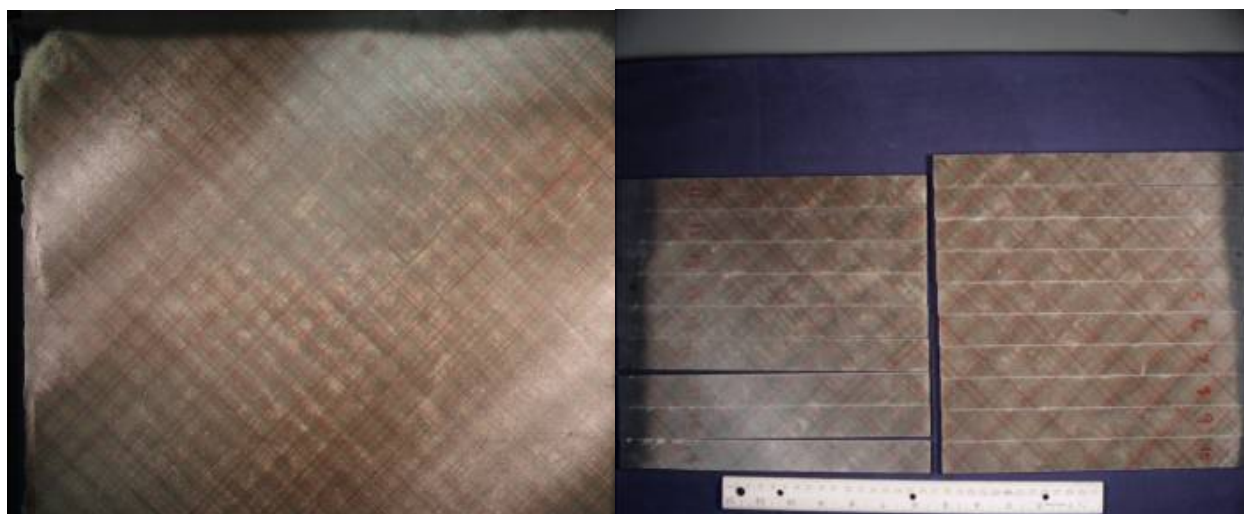


Figure 6. As-received 5216 E glass panel F.



Figure 7. As-received 5216 S glass panel A.



Figure 8. As-received 5216 S glass panel B.

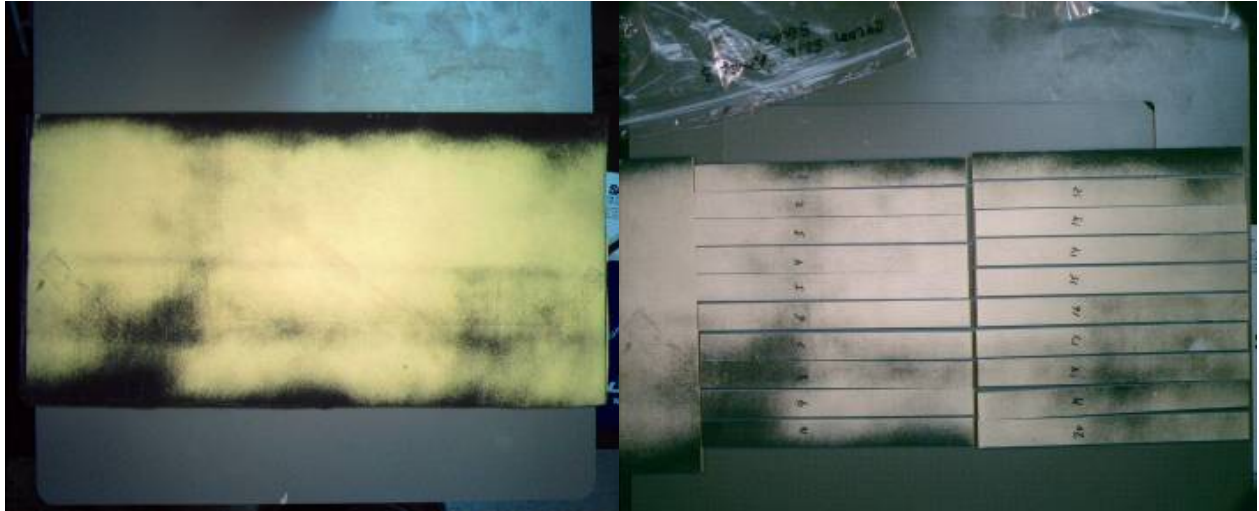


Figure 9. As-received 5216 S glass panel C.



Figure 10. As-received 5216 S glass panel D.

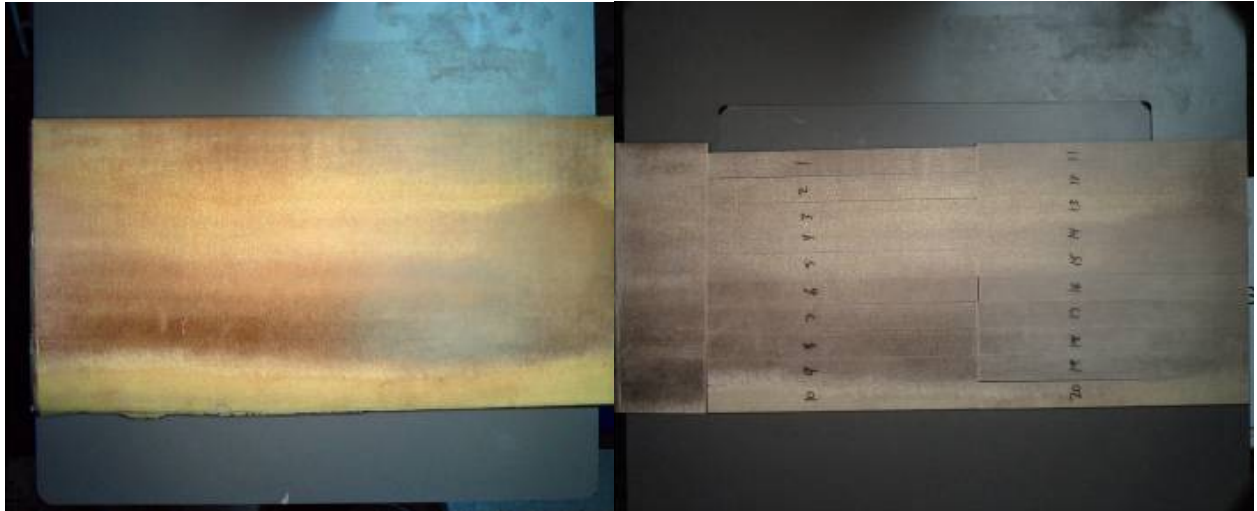


Figure 11. As-received 5216 S glass panel E.



Figure 12. As-received 5216 S glass panel F.

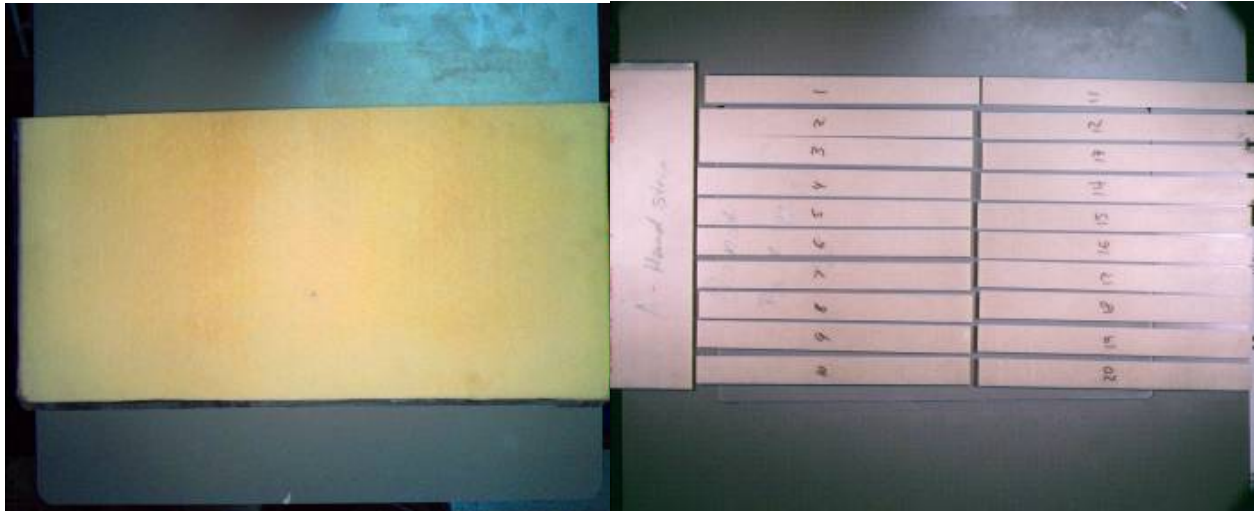


Figure 13. As-received 114 E glass panel A.

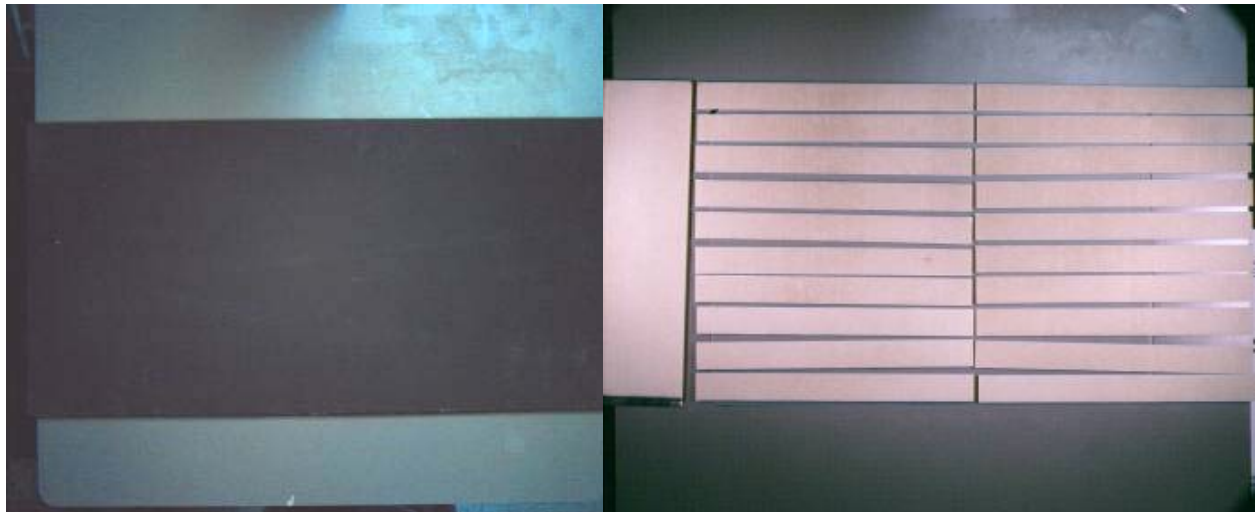


Figure 14. As-received 114 E glass panel B.

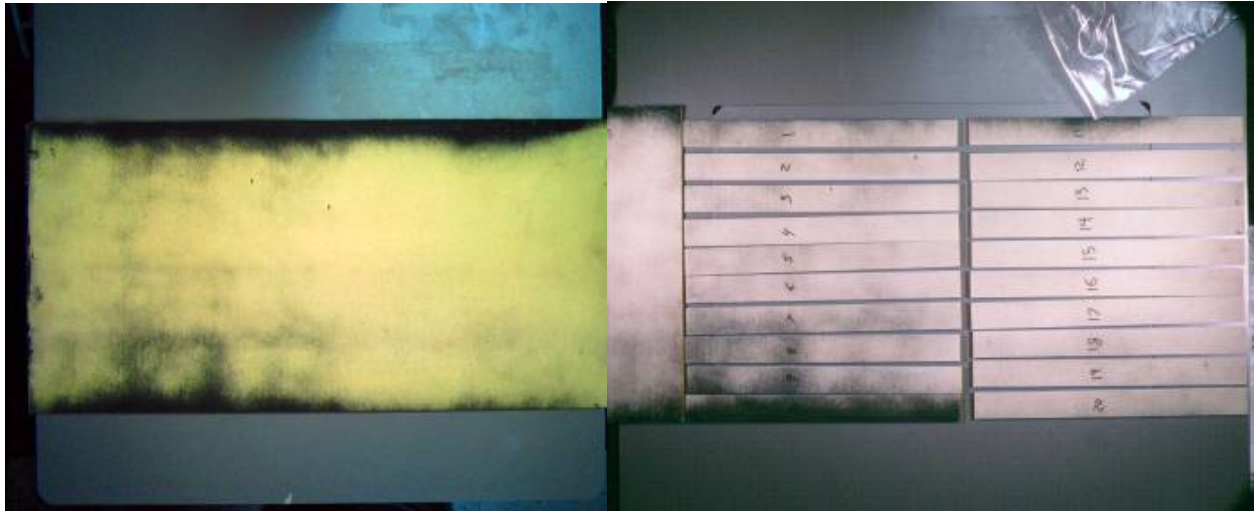


Figure 15. As-received 114 E glass panel C.

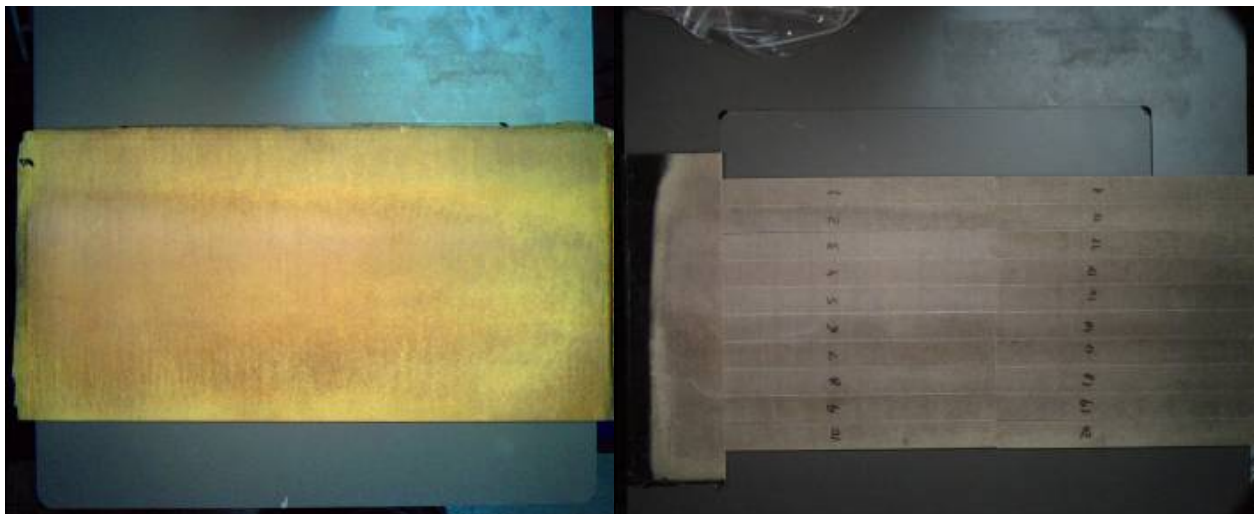


Figure 16. As-received 114 E glass panel D.

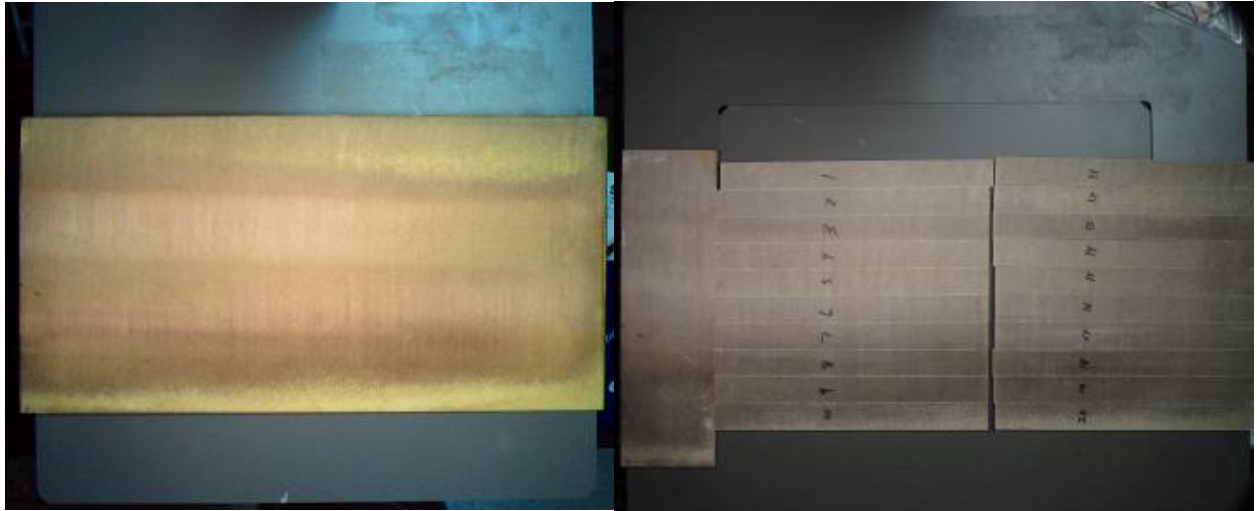


Figure 17. As-received 114 E glass panel E.

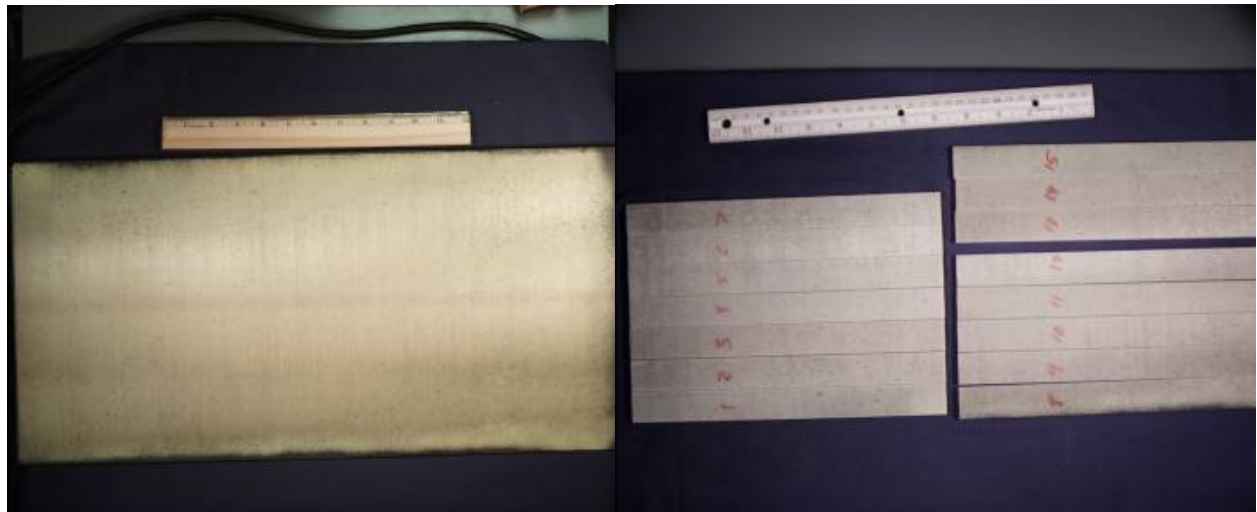


Figure 18. As-received 114 E glass panel F.

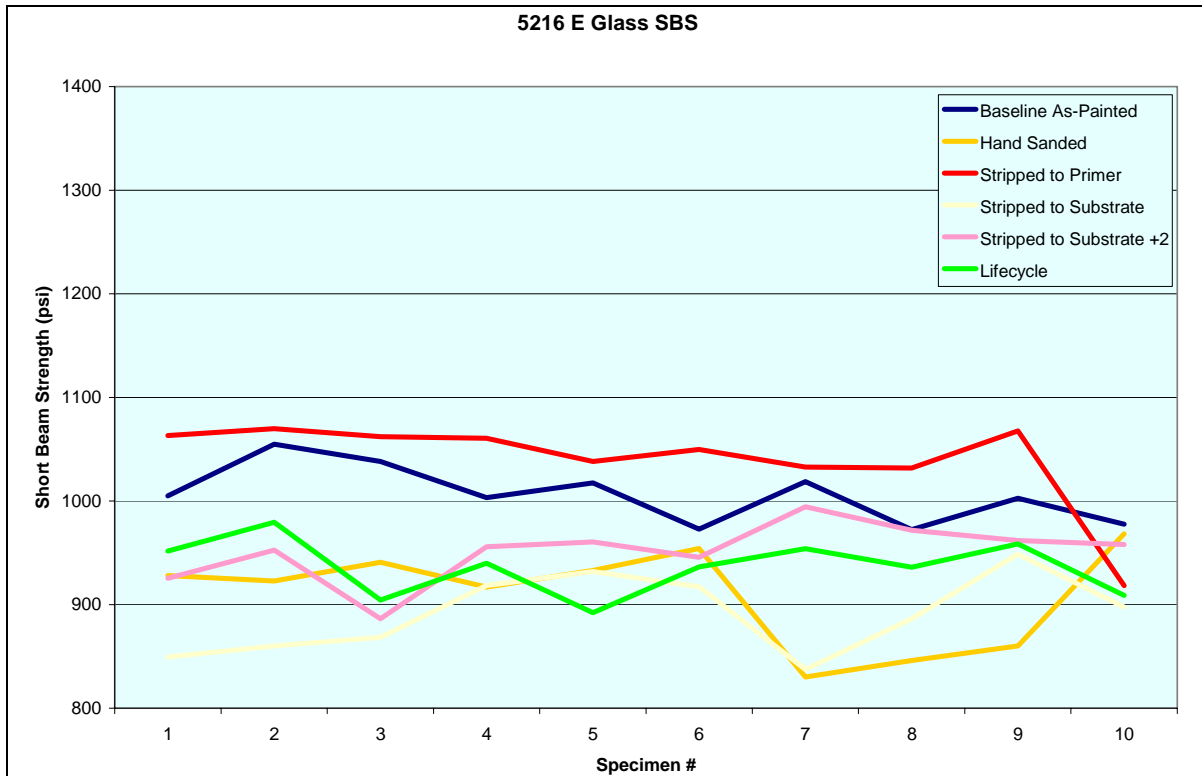


Figure 19. Short-beam shear test results for 5216 E glass.

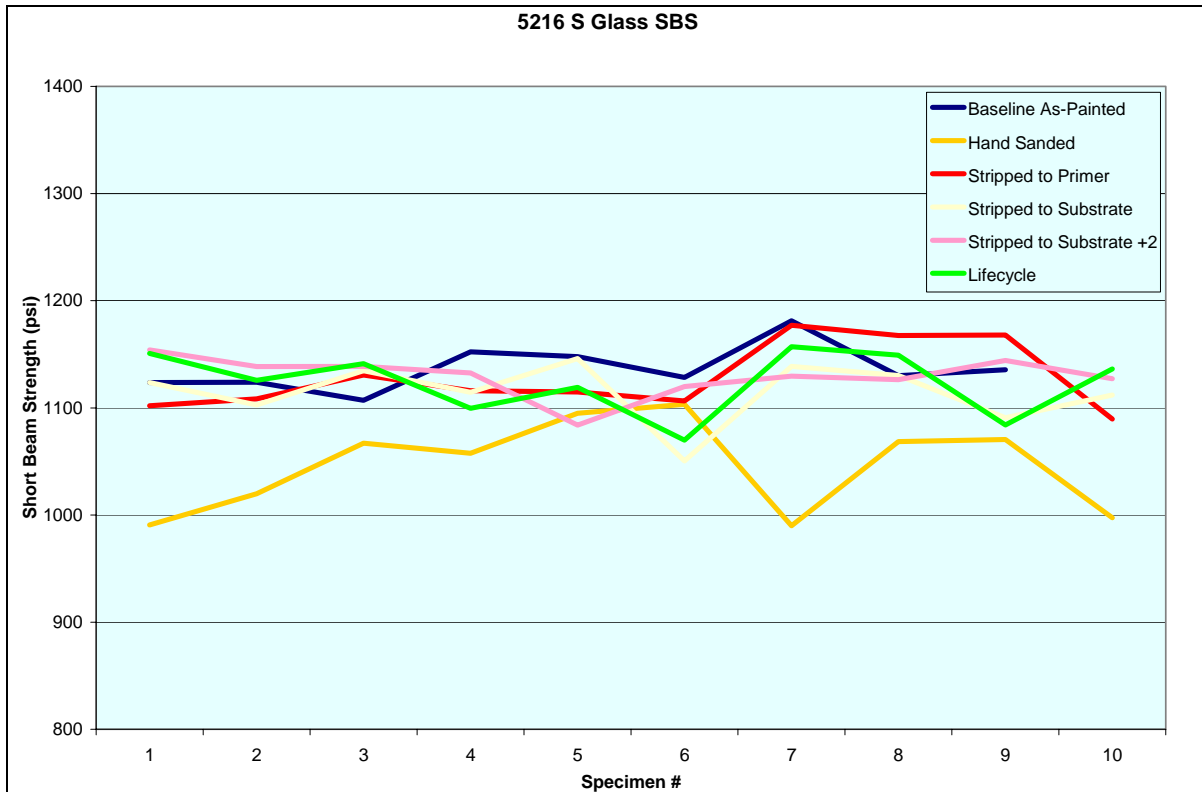


Figure 20. Short-beam shear test results for 5216 S glass.

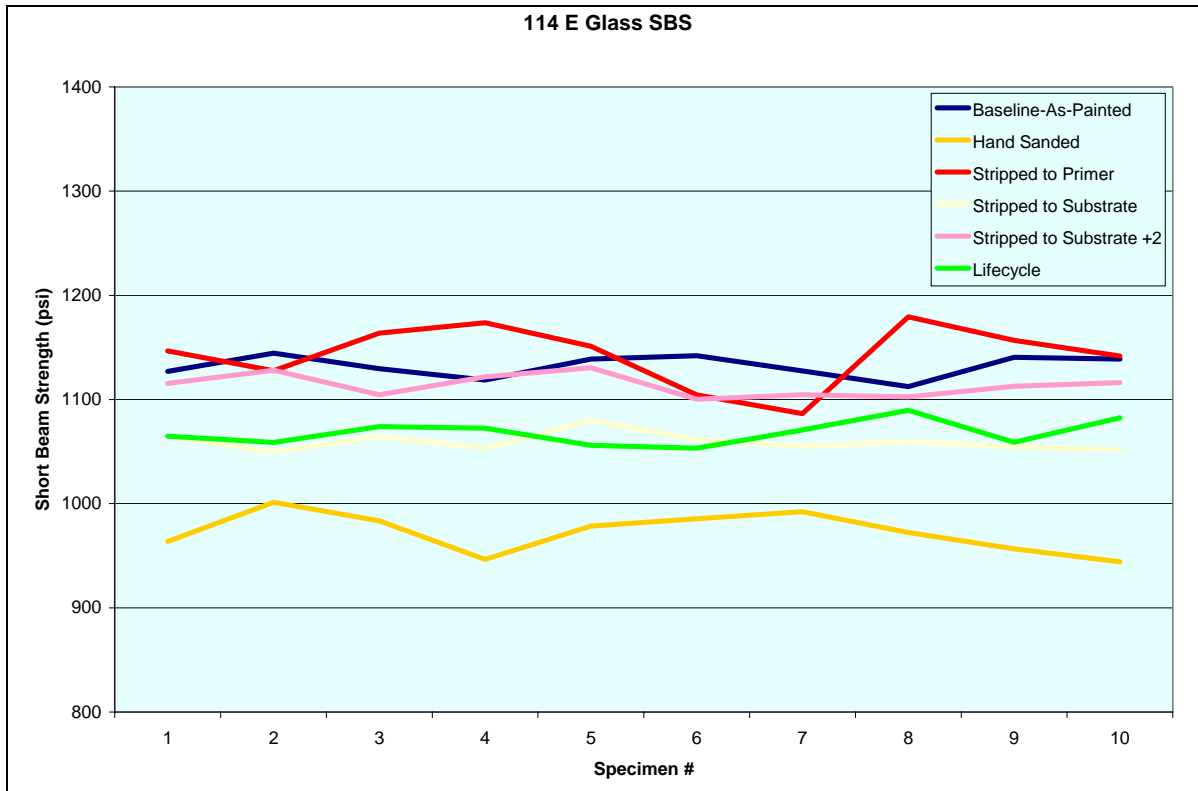


Figure 21. Short-beam shear test results for 114 E glass.

Table 3. Short-beam shear results.

Material	Test Group	Average Short Beam Shear Strength (PSI)	Standard Deviation
5216 E Glass	Baseline as-painted	1006.3	27.4
5216 E Glass	Hand sanded	910	47.6
5216 E Glass	Stripped to primer	1039.4	44.9
5216 E Glass	Stripped to substrate	891.6	37.4
5216 E Glass	Stripped to substrate plus two	951.2	28.8
5216 E Glass	Lifecycle	934.8	25.7
5216 S Glass	Baseline as-painted	1136	21.5
5216 S Glass	Hand sanded	1046	43.0
5216 S Glass	Stripped to primer	1128	31.5
5216 S Glass	Stripped to substrate	1114.4	28.1
5216 S Glass	Stripped to substrate plus two	1129.5	18.8
5216 S Glass	Lifecycle	1128.2	28.4
114 E Glass	Baseline as-painted	1131.4	15.0
114 E Glass	Hand sanded	972.5	19.3
114 E Glass	Stripped to primer	1143.1	29.6
114 E Glass	Stripped to substrate	1059.4	8.9
114 E Glass	Stripped to substrate plus two	1113.7	10.7
114 E Glass	Lifecycle	1068.1	11.9

## 4.2 Tensile Testing

The tensile results are presented in figures 22–24 and also tabulated in table 4. Generally, the “baseline” and “stripped-to-primer” groups had the highest tensile values observed, and the “hand-sanded” group had the lowest strength values.

## 4.3 Fatigue Testing

The fatigue results are presented in figures 25–27 and in tabular form in tables 5–7. It can be observed in the data that the “baseline” and “stripped-to-primer” groups performed the best under the applied fatigue stresses. The “stripped-to-substrate plus two” and “lifecycle” groups were the poorest performers under these conditions.

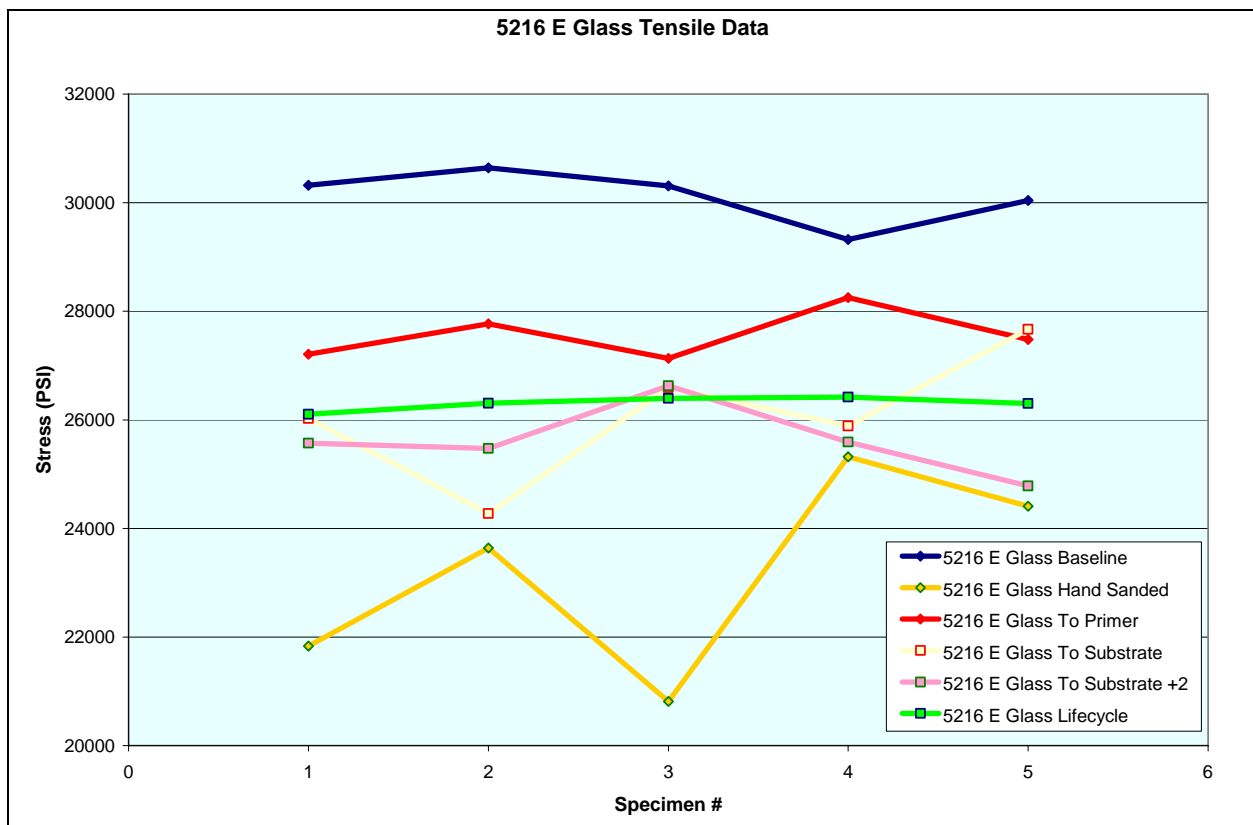


Figure 22. Tensile test results for 5216 E glass.

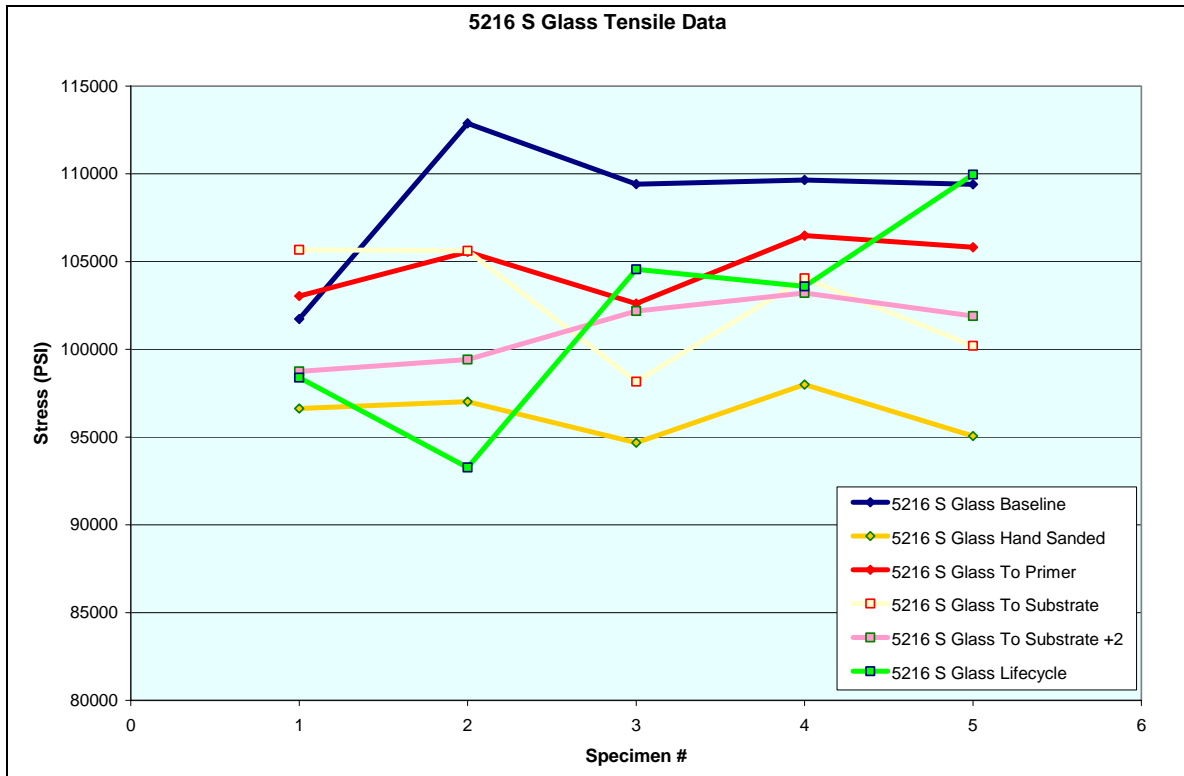


Figure 23. Tensile test results for 5216 S glass.

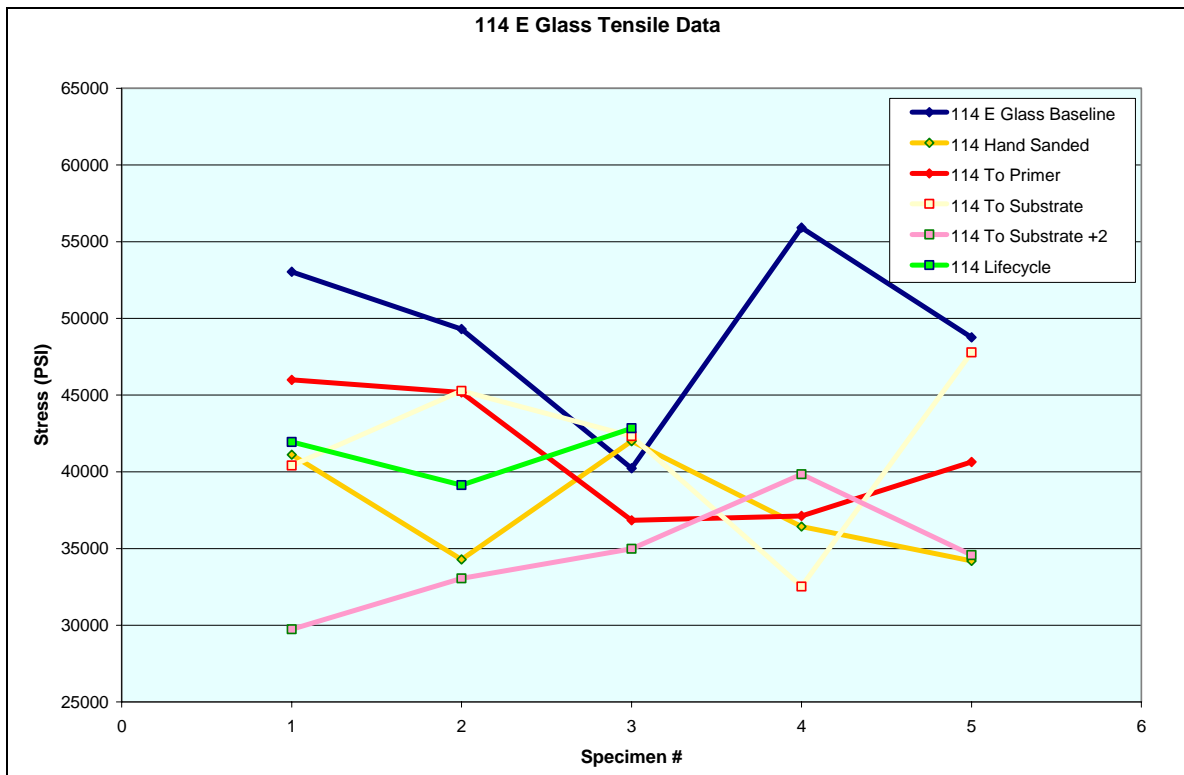


Figure 24. Tensile test results for 114 E glass.

Table 4. Tensile testing results.

Material	Test Group	Average Tensile Strength (PSI)	Standard Deviation
5216 E Glass	Baseline as-painted	30224	157
5216 E Glass	Hand sanded	23295	1323
5216 E Glass	Stripped to primer	27461	319
5216 E Glass	Stripped to substrate	26170	373
5216 E Glass	Stripped to substrate plus two	25545	63
5216 E Glass	Lifecycle	26355	52
5216 S Glass	Baseline as-painted	109487	140
5216 S Glass	Hand sanded	96237	1256
5216 S Glass	Stripped to primer	104802	1533
5216 S Glass	Stripped to substrate	103284	2782
5216 S Glass	Stripped to substrate plus two	101168	1519
5216 S Glass	Lifecycle	102174	3315
114 E Glass	Baseline as-painted	50371	2330
114 E Glass	Hand sanded	37277	3489
114 E Glass	Stripped to primer	40984	4038
114 E Glass	Stripped to substrate	42666	2449
114 E Glass	Stripped to substrate plus two	34200	1013
114 E Glass	Lifecycle	41309	1935

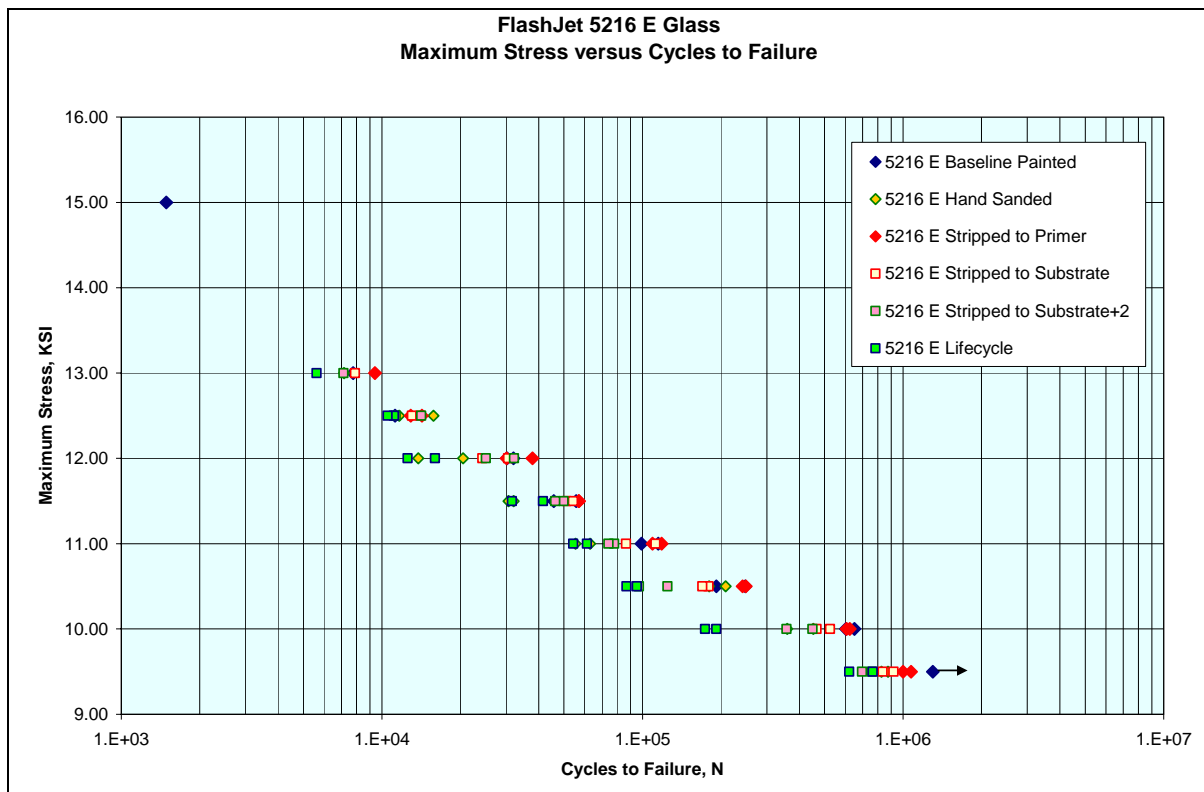


Figure 25. Fatigue test results for 5216 E glass.

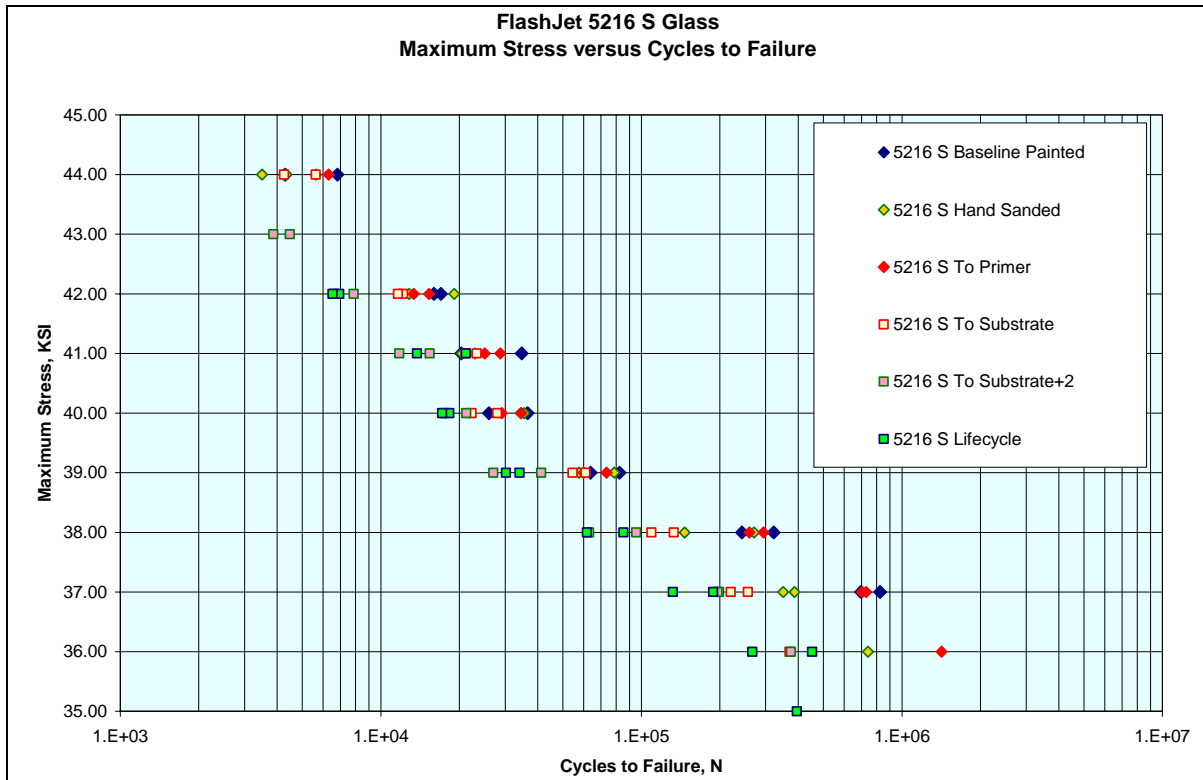


Figure 26. Fatigue test results for 5216 S glass.

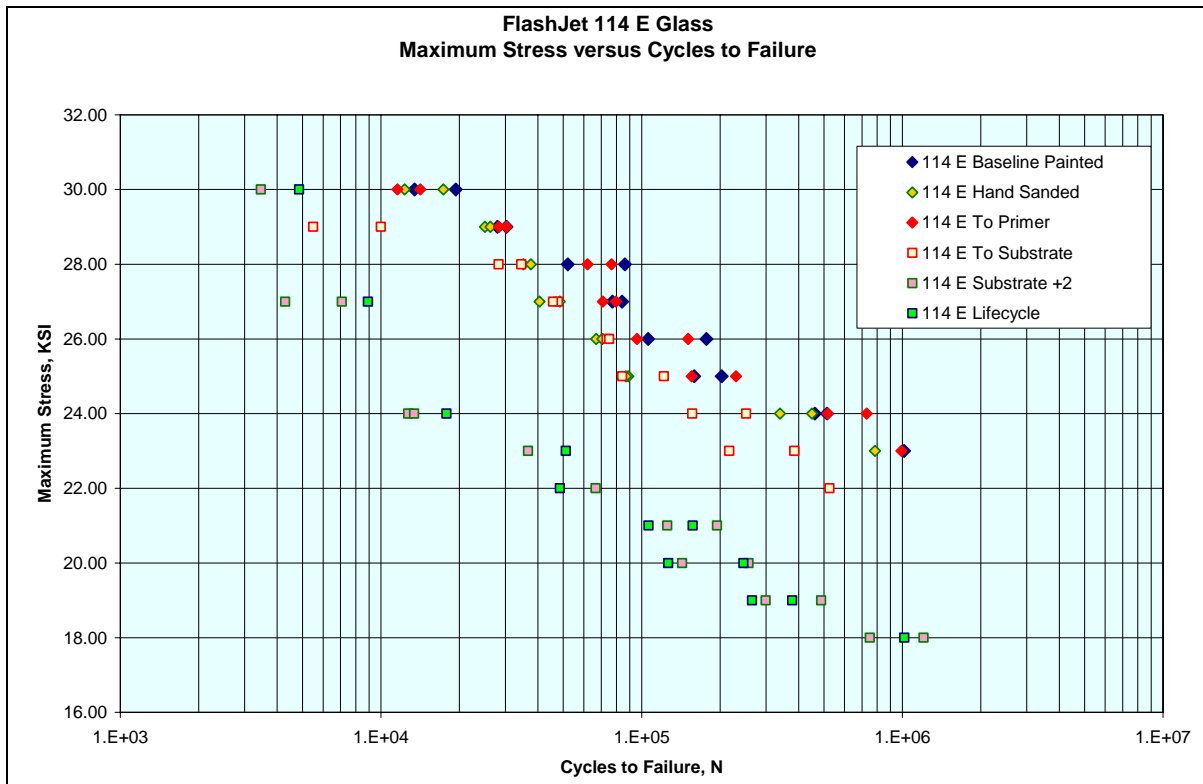


Figure 27. Fatigue test results for 114 E glass.

Table 5. Fatigue results for 5216 E glass.

Specimen No.	Material	Group	Max Stress (KSI)	Mean Stress (KSI)	Min Stress (KSI)	Stress Amplitude (KSI)	R-Value	Cycles
5E-B2	5216 E	Baseline	—	0.000	0.0	0.0	—	—
5E-B3	5216 E	Baseline	15.00	8.250	1.5	6.8	0.1	1,490
5E-B4	5216 E	Baseline	9.50	5.225	1.0	4.3	0.1	1,300,000
5E-B6	5216 E	Baseline	11.50	6.325	1.2	5.2	0.1	45,642
5E-B7	5216 E	Baseline	11.50	6.325	1.2	5.2	0.1	55,676
5E-B8	5216 E	Baseline	13.00	7.150	1.3	5.9	0.1	7,762
5E-B10	5216 E	Baseline	10.50	5.775	1.1	4.7	0.1	248,330
5E-B11	5216 E	Baseline	12.00	6.600	1.2	5.4	0.1	30,226
5E-B12	5216 E	Baseline	12.00	6.600	1.2	5.4	0.1	32,000
5E-B13	5216 E	Baseline	10.00	5.500	1.0	4.5	0.1	603,920
5E-B15	5216 E	Baseline	10.00	5.500	1.0	4.5	0.1	650,843
5E-B16	5216 E	Baseline	11.00	6.050	1.1	5.0	0.1	99,119
5E-B17	5216 E	Baseline	11.00	6.050	1.1	5.0	0.1	114,909
5E-B19	5216 E	Baseline	12.50	6.875	1.3	5.6	0.1	11,233
5E-B20	5216 E	Baseline	10.50	5.775	1.1	4.7	0.1	191,944
5E-A1	5216 E	Hand sanded	13.00	7.150	1.3	5.9	0.1	7,156
5E-A2	5216 E	Hand sanded	12.50	6.875	1.3	5.6	0.1	11,657
5E-A3	5216 E	Hand sanded	12.50	6.875	1.3	5.6	0.1	15,784
5E-A4	5216 E	Hand sanded	12.00	6.600	1.2	5.4	0.1	20,494
5E-A5	5216 E	Hand sanded	12.00	6.600	1.2	5.4	0.1	13,807
5E-A6	5216 E	Hand sanded	11.50	6.325	1.2	5.2	0.1	32,016
5E-A7	5216 E	Hand sanded	11.50	6.325	1.2	5.2	0.1	30,621
5E-A8	5216 E	Hand sanded	11.00	6.050	1.1	5.0	0.1	55,399
5E-A11	5216 E	Hand sanded	11.00	6.050	1.1	5.0	0.1	62,931
5E-A12	5216 E	Hand sanded	10.50	5.775	1.1	4.7	0.1	208,420
5E-A13	5216 E	Hand sanded	10.50	5.775	1.1	4.7	0.1	180,432
5E-A14	5216 E	Hand sanded	10.00	5.500	1.0	4.5	0.1	358,859
5E-A16	5216 E	Hand sanded	10.00	5.500	1.0	4.5	0.1	452,986
5E-A17	5216 E	Hand sanded	9.50	5.225	1.0	4.3	0.1	826,419
5E-A18	5216 E	Hand sanded	9.50	5.225	1.0	4.3	0.1	874,591
5E-C1	5216 E	To primer	13.00	7.150	1.3	5.9	0.1	9,402
5E-C3	5216 E	To primer	12.50	6.875	1.3	5.6	0.1	14,244
5E-C4	5216 E	To primer	12.50	6.875	1.3	5.6	0.1	12,896
5E-C5	5216 E	To primer	12.00	6.600	1.2	5.4	0.1	30,142
5E-C6	5216 E	To primer	12.00	6.600	1.2	5.4	0.1	37,831
5E-C7	5216 E	To primer	11.50	6.325	1.2	5.2	0.1	56,899
5E-C8	5216 E	To primer	11.50	6.325	1.2	5.2	0.1	57,018
5E-C9	5216 E	To primer	11.00	6.050	1.1	5.0	0.1	109,187
5E-C10	5216 E	To primer	11.00	6.050	1.1	5.0	0.1	118,462
5E-C11	5216 E	To primer	10.50	5.775	1.1	4.7	0.1	241,980
5E-C13	5216 E	To primer	10.50	5.775	1.1	4.7	0.1	248,919
5E-C16	5216 E	To primer	10.00	5.500	1.0	4.5	0.1	623,713
5E-C17	5216 E	To primer	10.00	5.500	1.0	4.5	0.1	606,532
5E-C18	5216 E	To primer	9.50	5.225	1.0	4.3	0.1	1,072,564
5E-C19	5216 E	To primer	9.50	5.225	1.0	4.3	0.1	999,311
5E-D1	5216 E	To substrate	13.00	7.150	1.3	5.9	0.1	7,894
5E-D3	5216 E	To substrate	12.50	6.875	1.3	5.6	0.1	13,038

Table 5. Fatigue results for 5216 E glass (continued).

Specimen No.	Material	Group	Max Stress (KSI)	Mean Stress (KSI)	Min Stress (KSI)	Stress Amplitude (KSI)	R-Value	Cycles
5E-D4	5216 E	To substrate	12.50	6.875	1.3	5.6	0.1	14,062
5E-D5	5216 E	To substrate	12.00	6.600	1.2	5.4	0.1	30,493
5E-D6	5216 E	To substrate	12.00	6.600	1.2	5.4	0.1	24,285
5E-D7	5216 E	To substrate	11.50	6.325	1.2	5.2	0.1	51,139
5E-D8	5216 E	To substrate	11.50	6.325	1.2	5.2	0.1	54,183
5E-D9	5216 E	To substrate	11.00	6.050	1.1	5.0	0.1	86,582
5E-D10	5216 E	To substrate	11.00	6.050	1.1	5.0	0.1	112,272
5E-D11	5216 E	To substrate	10.50	5.775	1.1	4.7	0.1	179,155
5E-D12	5216 E	To substrate	10.50	5.775	1.1	4.7	0.1	169,898
5E-D14	5216 E	To substrate	10.00	5.500	1.0	4.5	0.1	524,376
5E-D15	5216 E	To substrate	10.00	5.500	1.0	4.5	0.1	465,435
5E-D18	5216 E	To substrate	9.50	5.225	1.0	4.3	0.1	835,426
5E-D19	5216 E	To substrate	9.50	5.225	1.0	4.3	0.1	919,256
5E-E1	5216 E	To substrate +2	13.00	7.150	1.3	5.9	0.1	7,118
5E-E2	5216 E	To substrate +2	12.50	6.875	1.3	5.6	0.1	14,155
5E-E3	5216 E	To substrate +2	12.50	6.875	1.3	5.6	0.1	11,315
5E-E4	5216 E	To substrate +2	12.00	6.600	1.2	5.4	0.1	25,100
5E-E5	5216 E	To substrate +2	12.00	6.600	1.2	5.4	0.1	32,158
5E-E7	5216 E	To substrate +2	11.50	6.325	1.2	5.2	0.1	49,878
5E-E11	5216 E	To substrate +2	11.50	6.325	1.2	5.2	0.1	46,302
5E-E12	5216 E	To substrate +2	11.00	6.050	1.1	5.0	0.1	77,906
5E-E13	5216 E	To substrate +2	11.00	6.050	1.1	5.0	0.1	74,152
5E-E14	5216 E	To substrate +2	10.50	5.775	1.1	4.7	0.1	97,016
5E-E15	5216 E	To substrate +2	10.50	5.775	1.1	4.7	0.1	124,767
5E-E16	5216 E	To substrate +2	10.00	5.500	1.0	4.5	0.1	357,130
5E-E17	5216 E	To substrate +2	10.00	5.500	1.0	4.5	0.1	449,304
5E-E18	5216 E	To substrate +2	9.50	5.225	1.0	4.3	0.1	758,426
5E-E19	5216 E	To substrate +2	9.50	5.225	1.0	4.3	0.1	695,851
5E-F2	5216 S	Lifecycle	9.50	5.225	1.0	4.3	0.1	765,842
5E-F4	5216 S	Lifecycle	9.50	5.225	1.0	4.3	0.1	621,916
5E-F5	5216 S	Lifecycle	10.00	5.500	1.0	4.5	0.1	191,919
5E-F6	5216 S	Lifecycle	10.00	5.500	1.0	4.5	0.1	174,089
5E-F7	5216 S	Lifecycle	10.50	5.775	1.1	4.7	0.1	95,189
5E-F9	5216 S	Lifecycle	10.50	5.775	1.1	4.7	0.1	86,824
5E-F10	5216 S	Lifecycle	11.00	6.050	1.1	5.0	0.1	61,284
5E-F11	5216 S	Lifecycle	11.00	6.050	1.1	5.0	0.1	54,220
5E-F12	5216 S	Lifecycle	11.50	6.325	1.2	5.2	0.1	41,524
5E-F14	5216 S	Lifecycle	11.50	6.325	1.2	5.2	0.1	31,582
5E-F15	5216 S	Lifecycle	12.00	6.600	1.2	5.4	0.1	15,987
5E-F16	5216 S	Lifecycle	12.00	6.600	1.2	5.4	0.1	12,568
5E-F17	5216 S	Lifecycle	12.50	6.875	1.3	5.6	0.1	11,123
5E-F18	5216 S	Lifecycle	12.50	6.875	1.3	5.6	0.1	10,524
5E-F20	5216 S	Lifecycle	13.00	7.150	1.3	5.9	0.1	5,619

Table 6. Fatigue results for 5216 S glass.

Specimen No.	Material	Group	Max Stress (KSI)	Mean Stress (KSI)	Min Stress (KSI)	Stress Amplitude (KSI)	R-Value	Cycles
5S-B1	5216 S	Baseline	50.00	27.500	5.0	45.0	0.1	—
5S-B2	5216 S	Baseline	38.00	20.900	3.8	34.2	0.1	243,544
5S-B3	5216 S	Baseline	38.00	20.900	3.8	34.2	0.1	322,251
5S-B4	5216 S	Baseline	39.00	21.450	3.9	35.1	0.1	82,566
5S-B5	5216 S	Baseline	39.00	21.450	3.9	35.1	0.1	63,854
5S-B8	5216 S	Baseline	40.00	22.000	4.0	36.0	0.1	26,020
5S-B9	5216 S	Baseline	40.00	22.000	4.0	36.0	0.1	36,575
5S-B10	5216 S	Baseline	41.00	22.550	4.1	36.9	0.1	20,345
5S-B11	5216 S	Baseline	41.00	22.550	4.1	36.9	0.1	34,740
5S-B12	5216 S	Baseline	42.00	23.100	4.2	37.8	0.1	17,006
5S-B14	5216 S	Baseline	42.00	23.100	4.2	37.8	0.1	15,986
5S-B15	5216 S	Baseline	37.00	20.350	3.7	33.3	0.1	824,466
5S-B16	5216 S	Baseline	37.00	20.350	3.7	33.3	0.1	695,996
5S-B17	5216 S	Baseline	44.00	24.200	4.4	39.6	0.1	4,296
5S-B18	5216 S	Baseline	44.00	24.200	4.4	39.6	0.1	6,808
5S-A1	5216 S	Hand sanded	36.00	19.800	3.6	32.4	0.1	740,876
5S-A3	5216 S	Hand sanded	38.00	20.900	3.8	34.2	0.1	146,592
5S-A4	5216 S	Hand sanded	38.00	20.900	3.8	34.2	0.1	270,658
5S-A5	5216 S	Hand sanded	39.00	21.450	3.9	35.1	0.1	57,628
5S-A6	5216 S	Hand sanded	39.00	21.450	3.9	35.1	0.1	78,683
5S-A7	5216 S	Hand sanded	40.00	22.000	4.0	36.0	0.1	35,492
5S-A8	5216 S	Hand sanded	40.00	22.000	4.0	36.0	0.1	34,447
5S-A9	5216 S	Hand sanded	41.00	22.550	4.1	36.9	0.1	22,994
5S-A10	5216 S	Hand sanded	41.00	22.550	4.1	36.9	0.1	20,450
5S-A12	5216 S	Hand sanded	42.00	23.100	4.2	37.8	0.1	19,153
5S-A14	5216 S	Hand sanded	42.00	23.100	4.2	37.8	0.1	12,825
5S-A16	5216 S	Hand sanded	37.00	20.350	3.7	33.3	0.1	387,260
5S-A17	5216 S	Hand sanded	37.00	20.350	3.7	33.3	0.1	350,569
5S-A18	5216 S	Hand sanded	44.00	24.200	4.4	39.6	0.1	4,345
5S-A19	5216 S	Hand sanded	44.00	24.200	4.4	39.6	0.1	3,505
5S-C1	5216 S	To primer	36.00	19.800	3.6	32.4	0.1	1,419,454
5S-C2	5216 S	To primer	37.00	20.350	3.7	33.3	0.1	704,151
5S-C3	5216 S	To primer	37.00	20.350	3.7	33.3	0.1	730,543
5S-C4	5216 S	To primer	38.00	20.900	3.8	34.2	0.1	294,672
5S-C5	5216 S	To primer	38.00	20.900	3.8	34.2	0.1	259,642
5S-C7	5216 S	To primer	39.00	21.450	3.9	35.1	0.1	60,044
5S-C8	5216 S	To primer	39.00	21.450	3.9	35.1	0.1	73,424
5S-C9	5216 S	To primer	40.00	22.000	4.0	36.0	0.1	34,568
5S-C10	5216 S	To primer	40.00	22.000	4.0	36.0	0.1	29,134
5S-C11	5216 S	To primer	41.00	22.550	4.1	36.9	0.1	25,034
5S-C12	5216 S	To primer	41.00	22.550	4.1	36.9	0.1	28,743
5S-C13	5216 S	To primer	42.00	23.100	4.2	37.8	0.1	15,314
5S-C14	5216 S	To primer	42.00	23.100	4.2	37.8	0.1	13,365
5S-C15	5216 S	To primer	44.00	24.200	4.4	39.6	0.1	5,631
5S-C19	5216 S	To primer	44.00	24.200	4.4	39.6	0.1	6,305
5S-D3	5216 S	To substrate	36.00	19.800	3.6	32.4	0.1	370,301

Table 6. Fatigue results for 5216 S glass (continued).

Specimen No.	Material	Group	Max Stress (KSI)	Mean Stress (KSI)	Min Stress (KSI)	Stress Amplitude (KSI)	R-Value	Cycles
5S-D4	5216 S	To substrate	37.00	20.350	3.7	33.3	0.1	256,542
5S-D5	5216 S	To substrate	37.00	20.350	3.7	33.3	0.1	220,417
5S-D6	5216 S	To substrate	38.00	20.900	3.8	34.2	0.1	133,269
5S-D7	5216 S	To substrate	38.00	20.900	3.8	34.2	0.1	109,363
5S-D8	5216 S	To substrate	39.00	21.450	3.9	35.1	0.1	54,524
5S-D9	5216 S	To substrate	39.00	21.450	3.9	35.1	0.1	61,040
5S-D10	5216 S	To substrate	40.00	22.000	4.0	36.0	0.1	22,315
5S-D11	5216 S	To substrate	40.00	22.000	4.0	36.0	0.1	27,971
5S-D12	5216 S	To substrate	41.00	22.550	4.1	36.9	0.1	21,168
5S-D15	5216 S	To substrate	41.00	22.550	4.1	36.9	0.1	23,330
5S-D17	5216 S	To substrate	42.00	23.100	4.2	37.8	0.1	12,185
5S-D18	5216 S	To substrate	42.00	23.100	4.2	37.8	0.1	11,647
5S-D19	5216 S	To substrate	44.00	24.200	4.4	39.6	0.1	5,625
5S-D20	5216 S	To substrate	44.00	24.200	4.4	39.6	0.1	4,253
5S-E5	5216 S	To substrate +2	36.00	19.800	3.6	32.4	0.1	375,054
5S-E7	5216 S	To substrate +2	37.00	20.350	3.7	33.3	0.1	198,862
5S-E8	5216 S	To substrate +2	37.00	20.350	3.7	33.3	0.1	196,465
5S-E9	5216 S	To substrate +2	38.00	20.900	3.8	34.2	0.1	63,034
5S-E10	5216 S	To substrate +2	38.00	20.900	3.8	34.2	0.1	95,687
5S-E11	5216 S	To substrate +2	39.00	21.450	3.9	35.1	0.1	41,212
5S-E12	5216 S	To substrate +2	39.00	21.450	3.9	35.1	0.1	27,043
5S-E13	5216 S	To substrate +2	40.00	22.000	4.0	36.0	0.1	17,586
5S-E14	5216 S	To substrate +2	40.00	22.000	4.0	36.0	0.1	21,301
5S-E15	5216 S	To substrate +2	41.00	22.550	4.1	36.9	0.1	15,420
5S-E16	5216 S	To substrate +2	41.00	22.550	4.1	36.9	0.1	11,785
5S-E17	5216 S	To substrate +2	42.00	23.100	4.2	37.8	0.1	7,862
5S-E18	5216 S	To substrate +2	42.00	23.100	4.2	37.8	0.1	6,623
5S-E19	5216 S	To substrate +2	43.00	23.650	4.3	38.7	0.1	4,471
5S-E20	5216 S	To substrate +2	43.00	23.650	4.3	38.7	0.1	3,864
5S-F3	5216 S	Lifecycle	35.00	19.250	3.5	31.5	0.1	395,388
5S-F4	5216 S	Lifecycle	36.00	19.800	3.6	32.4	0.1	266,686
5S-F5	5216 S	Lifecycle	36.00	19.800	3.6	32.4	0.1	452,517
5S-F7	5216 S	Lifecycle	37.00	20.350	3.7	33.3	0.1	132,025
5S-F8	5216 S	Lifecycle	37.00	20.350	3.7	33.3	0.1	188,861
5S-F10	5216 S	Lifecycle	38.00	20.900	3.8	34.2	0.1	85,257
5S-F11	5216 S	Lifecycle	38.00	20.900	3.8	34.2	0.1	61,902
5S-F12	5216 S	Lifecycle	39.00	21.450	3.9	35.1	0.1	34,067
5S-F13	5216 S	Lifecycle	39.00	21.450	3.9	35.1	0.1	30,256
5S-F14	5216 S	Lifecycle	40.00	22.000	4.0	36.0	0.1	18,329
5S-F15	5216 S	Lifecycle	40.00	22.000	4.0	36.0	0.1	17,204
5S-F17	5216 S	Lifecycle	41.00	22.550	4.1	36.9	0.1	21,198
5S-F18	5216 S	Lifecycle	41.00	22.550	4.1	36.9	0.1	13,773
5S-F19	5216 S	Lifecycle	42.00	23.100	4.2	37.8	0.1	6,921
5S-F20	5216 S	Lifecycle	42.00	23.100	4.2	37.8	0.1	6,523

Table 7. Fatigue results for 114 E glass.

Specimen No.	Material	Group	Max Stress (KSI)	Mean Stress (KSI)	Min Stress (KSI)	Stress Amplitude (KSI)	R-Value	Cycles
114-B3	114	Baseline	23.00	12.650	2.3	10.350	0.1	1,015,489
114-B4	114	Baseline	24.00	13.200	2.4	10.800	0.1	513,758
114-B5	114	Baseline	24.00	13.200	2.4	10.800	0.1	461,617
114-B6	114	Baseline	25.00	13.750	2.5	11.250	0.1	202,588
114-B7	114	Baseline	25.00	13.750	2.5	11.250	0.1	159,098
114-B9	114	Baseline	26.00	14.300	2.6	11.700	0.1	105,775
114-B10	114	Baseline	26.00	14.300	2.6	11.700	0.1	177,098
114-B11	114	Baseline	27.00	14.850	2.7	12.150	0.1	77,256
114-B12	114	Baseline	27.00	14.850	2.7	12.150	0.1	84,092
114-B13	114	Baseline	28.00	15.400	2.8	12.600	0.1	86,174
114-B15	114	Baseline	28.00	15.400	2.8	12.600	0.1	52,074
114-B17	114	Baseline	29.00	15.950	2.9	13.050	0.1	30,291
114-B18	114	Baseline	29.00	15.950	2.9	13.050	0.1	27,980
114-B19	114	Baseline	30.00	16.500	3.0	13.500	0.1	13,462
114-B20	114	Baseline	30.00	16.500	3.0	13.500	0.1	19,359
114-A1	114	Hand sanded	23.00	12.650	2.3	10.350	0.1	785,065
114-A2	114	Hand sanded	24.00	13.200	2.4	10.800	0.1	449,825
114-A4	114	Hand sanded	24.00	13.200	2.4	10.800	0.1	339,289
114-A5	114	Hand sanded	26.00	14.300	2.6	11.700	0.1	66,933
114-A7	114	Hand sanded	26.00	14.300	2.6	11.700	0.1	70,609
114-A8	114	Hand sanded	28.00	15.400	2.8	12.600	0.1	35,154
114-A9	114	Hand sanded	28.00	15.400	2.8	12.600	0.1	37,572
114-A10	114	Hand sanded	29.00	15.950	2.9	13.050	0.1	25,038
114-A12	114	Hand sanded	29.00	15.950	2.9	13.050	0.1	26,303
114-A13	114	Hand sanded	30.00	16.500	3.0	13.500	0.1	12,322
114-A14	114	Hand sanded	30.00	16.500	3.0	13.500	0.1	17,323
114-A16	114	Hand sanded	27.00	14.850	2.7	12.150	0.1	40,571
114-A18	114	Hand sanded	25.00	13.750	2.5	11.250	0.1	88,825
114-A19	114	Hand sanded	25.00	13.750	2.5	11.250	0.1	87,053
114-A20	114	Hand sanded	27.00	14.850	2.7	12.150	0.1	48,526
114-C2	114	To primer	23.00	12.650	2.3	10.350	0.1	992,004
114-C3	114	To primer	24.00	13.200	2.4	10.800	0.1	516,785
114-C4	114	To primer	24.00	13.200	2.4	10.800	0.1	730,055
114-C5	114	To primer	25.00	13.750	2.5	11.250	0.1	155,624
114-C6	114	To primer	25.00	13.750	2.5	11.250	0.1	230,304
114-C7	114	To primer	26.00	14.300	2.6	11.700	0.1	95,848
114-C8	114	To primer	26.00	14.300	2.6	11.700	0.1	150,668
114-C9	114	To primer	27.00	14.850	2.7	12.150	0.1	79,672
114-C13	114	To primer	27.00	14.850	2.7	12.150	0.1	71,002
114-C15	114	To primer	28.00	15.400	2.8	12.600	0.1	62,000
114-C16	114	To primer	28.00	15.400	2.8	12.600	0.1	76,593
114-C17	114	To primer	29.00	15.950	2.9	13.050	0.1	30,296
114-C18	114	To primer	29.00	15.950	2.9	13.050	0.1	28,315
114-C19	114	To primer	30.00	16.500	3.0	13.500	0.1	11,565
114-C20	114	To primer	30.00	16.500	3.0	13.500	0.1	14,149
114-D1	114	To substrate	23.00	12.650	2.3	10.350	0.1	216,676

Table 7. Fatigue results for 114 E glass (continued).

Specimen No.	Material	Group	Max Stress (KSI)	Mean Stress (KSI)	Min Stress (KSI)	Stress Amplitude (KSI)	R-Value	Cycles
114-D2	114	To substrate	24.00	13.200	2.4	10.800	0.1	156,362
114-D3	114	To substrate	24.00	13.200	2.4	10.800	0.1	251,655
114-D4	114	To substrate	25.00	13.750	2.5	11.250	0.1	121,664
114-D5	114	To substrate	25.00	13.750	2.5	11.250	0.1	84,215
114-D7	114	To substrate	26.00	14.300	2.6	11.700	0.1	73,431
114-D9	114	To substrate	26.00	14.300	2.6	11.700	0.1	75,061
114-D10	114	To substrate	27.00	14.850	2.7	12.150	0.1	47,781
114-D12	114	To substrate	27.00	14.850	2.7	12.150	0.1	45,687
114-D13	114	To substrate	28.00	15.400	2.8	12.600	0.1	28,302
114-D14	114	To substrate	28.00	15.400	2.8	12.600	0.1	34,512
114-D15	114	To substrate	29.00	15.950	2.9	13.050	0.1	5,504
114-D18	114	To substrate	29.00	15.950	2.9	13.050	0.1	10,002
114-D19	114	To substrate	23.00	12.650	2.3	10.350	0.1	385,125
114-D20	114	To substrate	22.00	12.100	2.2	9.900	0.1	525,645
114-E4	114	To substrate +2	23.00	12.650	2.3	10.350	0.1	36,666
114-E5	114	To substrate +2	24.00	13.200	2.4	10.800	0.1	12,719
114-E6	114	To substrate +2	24.00	13.200	2.4	10.800	0.1	13,410
114-E7	114	To substrate +2	19.00	10.450	1.9	8.550	0.1	488,903
114-E9	114	To substrate +2	19.00	10.450	1.9	8.550	0.1	298,786
114-E10	114	To substrate +2	20.00	11.000	2.0	9.000	0.1	142,864
114-E11	114	To substrate +2	20.00	11.000	2.0	9.000	0.1	256,874
114-E13	114	To substrate +2	27.00	14.850	2.7	12.150	0.1	7,079
114-E14	114	To substrate +2	27.00	14.850	2.7	12.150	0.1	4,294
114-E15	114	To substrate +2	18.00	9.900	1.8	8.100	0.1	750,899
114-E16	114	To substrate +2	18.00	9.900	1.8	8.100	0.1	1,205,876
114-E17	114	To substrate +2	21.00	11.550	2.1	9.450	0.1	125,378
114-E18	114	To substrate +2	21.00	11.550	2.1	9.450	0.1	194,528
114-E19	114	To substrate +2	22.00	12.100	2.2	9.900	0.1	66,619
114-E20	114	To substrate +2	30.00	16.500	3.0	13.500	0.1	3,463
114-F1	114	Lifecycle	18.00	9.900	1.8	8.100	0.1	1,016,958
114-F2	114	Lifecycle	19.00	10.450	1.9	8.550	0.1	265,481
114-F3	114	Lifecycle	19.00	10.450	1.9	8.550	0.1	378,456
114-F4	114	Lifecycle	20.00	11.000	2.0	9.000	0.1	245,826
114-F5	114	Lifecycle	20.00	11.000	2.0	9.000	0.1	126,426
114-F6	114	Lifecycle	21.00	11.550	2.1	9.450	0.1	106,231
114-F7	114	Lifecycle	21.00	11.550	2.1	9.450	0.1	156,987
114-F10	114	Lifecycle	22.00	12.100	2.2	9.900	0.1	48,591
114-F11	114	Lifecycle	23.00	12.650	2.3	10.350	0.1	51,211
114-F12	114	Lifecycle	24.00	13.200	2.4	10.800	0.1	17,845
114-F13	114	Lifecycle	27.00	14.850	2.7	12.150	0.1	8,915
114-F14	114	Lifecycle	30.00	16.500	3.0	13.500	0.1	4,853

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## **5. Discussion**

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### **5.1 Short-Beam Shear**

It can be observed in the data that the hand-sanding process is somewhat detrimental to the short-beam shear strength of the composites tested in this work. It appears that, although this is an approved process, there are surface effects of the sanding that leave residual conditions which tend to decrease overall shear strength. Although this decrease is not overwhelming, ~10% for the composites tested, it is statistically significant. The ramifications of imparting this strength decrease on the materials have obviously not been significant enough to cause catastrophic service failure of the rotor blades during flight. The long-term effects of this decrease are unknown. The FlashJet process appears to only slightly affect the short-beam shear strength of these composite materials. The decrease from the baseline was less than that of the hand-sanding process. It does appear that, in general, the more aggressive the FlashJet processing, the more substantial the decrease in strength becomes. This is demonstrated by comparing the groups that completely remove the paint to the group that does not, the “stripped-to-primer” group. In all cases, the “stripped-to-primer” group was the best performer among the FlashJet groups. Indeed, it appears that utilizing FlashJet to strip the topcoat does not significantly reduce the short-beam shear strength of these composite materials at all. All FlashJet groups outperformed the current hand-sanding process in short-beam shear testing.

### **5.2 Tensile Testing**

The data suggests that the hand-sanding process currently being utilized at CCAD is somewhat detrimental to the overall tensile strength of the composite materials. The reduction in tensile strength varied from 15%–25% across the groups but was statistically significant. Only five samples were tested from each group and there was a high degree of scatter in the data, so tremendous weight should not be given to this apparent trend. The FlashJet groups performed better than the hand-sanded group under tensile testing. Their tensile strength results were equal to or only slightly lower than the baseline group. It did not appear that the FlashJet process significantly reduced the tensile strength of the composite materials tested.

### **5.3 Fatigue Testing**

In contrast to the short beam shear and tensile testing, there appeared to be significant detrimental effects of the FlashJet process on the fatigue strength of the composite materials tested when removal to the substrate was performed. The trends were uniform and consistent across the materials. The “stripped-to-substrate plus two” and “lifecycle” groups performed significantly below the others. It would appear that the more intense and aggressive the FlashJet process is, the more significant the fatigue-life reduction. Although these groups were included only to assess what could happen if something went wrong over the lifetime of the component, it

revealed that the FlashJet process certainly had the inherent ability to cause damage. CCAD had significant difficulties optimizing the FlashJet parameters for removal of both the topcoat and especially the primer. It can be observed in the photos that the removal of the coating system was not uniform. This may be caused by several factors including those dependent on the system itself, e.g., the xenon bulb, voltage consistency, etc. Regardless, if it is necessary to completely remove the primer for the maintenance and overhaul processing, then significant improvements on uniformity and consistency will have to happen before FlashJet is a viable option. In contrast, using FlashJet to remove just the topcoat appears to leave the substrate unaffected. The “stripped-to-primer” group performed on par with the baseline group. This would suggest that the detrimental effects of the FlashJet on these composite materials were, although significant, very superficial as the primer is only 0.001–0.0015 in thick. Optimization of the FlashJet parameters would improve the performance. It is unknown, however, whether the FlashJet process will prove nimble or repeatable enough to remove just the primer consistently without damaging the substrates. That certainly was not the case within this study. It may be that experience and understanding of the system will improve the overall long-term performance.

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## **6. Conclusions**

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The hand-sanding process appears to impart a slight detrimental reduction in both short-beam shear and tensile strength of the materials tested. The long-term effects of this reduction are unknown, but do not appear to be largely significant since there have been no service failures. The fatigue performance is ever so slightly reduced by the hand-sanding process.

The effects of the FlashJet process are almost insignificant on the short-beam shear and tensile strength of the materials. However, in fatigue, the detrimental effects become readily apparent. Stripping to the substrate over the life of the component or performing just two additional passes over a paint-free area significantly reduces the fatigue strength of these materials. If the FlashJet is utilized to just remove the topcoat and no contact with the substrate is made, then the detrimental effects disappear. Therefore, either considerable optimization of the system must take place, or the utilization of the system must be confined to just removal of the topcoat. In either case, repeatability of the system will have to be addressed as, in its present condition, it does not appear nimble enough to remove the primer evenly without imparting damage.

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